

**New Radiation Sources through Generation and Resonant Enhancement of
Current Driven Plasma Instabilities in Lower Dimensional Solid State
Systems.**

Final Report

U.S. Army Research Office
Grant number: DAAH04-93-G-0259

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NTIS	CRA&I <input checked="" type="checkbox"/>
DTIC	TAB <input type="checkbox"/>
Unannounced <input type="checkbox"/>	
Justification _____	
By _____	
Distribution / _____	
Availability Codes	
Dist	Avail and/or Special
A-1	

September 1994

19950203 347

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED	
	September 1994	FINAL REPORT July 1993 to June 1994	
4. TITLE AND SUBTITLE		5. FUNDING NUMBERS	
New Radiation Sources through Generation and Resonant Enhancement of Current Driven Plasma Instabilities in Lower Dimensional Solid State Systems		DAAH04-93-G-0259	
6. AUTHOR(S)			
P. Bakshi and K. Kempa			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)		8. PERFORMING ORGANIZATION REPORT NUMBER	
Physics Department Boston College Chestnut Hill, MA 02167		S DTIC ELECTE FEB 13 1995 D	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211		ARO 30935.1-PH	
11. SUPPLEMENTARY NOTES			
The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.			
12a. DISTRIBUTION/AVAILABILITY STATEMENT		12b. DISTRIBUTION CODE	
Approved for public release; distribution unlimited.			
13. ABSTRACT (Maximum 200 words)			
<p>In this program, we have identified theoretically the most promising candidates for current driven plasma instabilities (CDPI) in semiconductor based systems: the modulated quantum wires and lateral surface superlattices (LSSL). Feasibility of CDPI at much lower driving fields, as compared to the corresponding uniform systems, was established. Investigation of CDPI in a superconducting system was continued in close collaboration with an experimental group. We have also developed contacts with a number of experimental groups to stimulate parallel efforts for verification of CDPI in layered semiconductor systems. A Workshop was arranged with ARO sponsorship, held at Boston College in August 1994, which brought together Dr. Ciftan (ARO), our group, and the experimentalists to discuss future efforts and collaborations.</p>			
14. SUBJECT TERMS		15. NUMBER OF PAGES	
current driven plasma instabilities, modulated quantum wires, lateral surface superlattices, superconducting layers, grating coupler, millimeter and submillimeter waves, device applications, emission of radiation.		6	
16. PRICE CODE			
17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

I. Introduction

In this program we have studied a new promising system, suitable for experimental verification and device applications of current driven plasma instabilities (CDPI) in solid state systems. This system is based on the idea of *periodic modulation* of the carrier density, which can be achieved by applying a periodic grid (grating) over the lower dimensional system (2DEG or 1DEG), or by periodic etching. Our paper¹ on "Current-driven plasma instabilities in modulated lower-dimensional systems", was published during this grant period. While this paper was submitted for publication earlier, it was revised, and finally accepted, during this grant period. We have shown the feasibility of current-driven plasma instabilities in modulated lower-dimensional systems at much lower driving fields, as compared to the corresponding uniform systems.

We have also continued investigation of CDPI in a superconducting system² in close collaboration with an experimental group.

In a subsequent contribution, submitted as an abstract for the APS 1994 March Meeting³, we extended the arguments to modulated 1DEG with arbitrary potentials, and also to lateral surface superlattices (LSSL). A paper for publication is under preparation.

We have also developed contacts with a number of experimental groups to stimulate parallel efforts for verification of CDPI in layered semiconductor systems. A Workshop was arranged with ARO sponsorship, held at Boston College in August 1994, which brought together Dr. Ciftan (ARO), our group, and the experimentalists to discuss future efforts and collaborations.

Section II provides a statement of the problems studied, section III summarizes the most important results and the last section lists the publications, and participating scientific personnel.

II. Statement of the Problem

The basic problem investigated in this program was a study of CDPI in modulated solid state systems, leading to a novel approach for generation or amplification of electromagnetic radiation in the millimeter and submillimeter ranges, with potential applications to a new class of devices.

The basic principle is to utilize the energy of a dc current passing through a plasma, which leads to a plasma-instability. The instability mechanism transfers the energy from the current to characteristic plasma waves which grow in amplitude. These waves, in turn, can radiatively decay by interaction with a grating, emitting electromagnetic radiation in a predictable frequency range.

In an earlier program we had studied high mobility, lower dimensional, *uniform* systems as the solid state media for achieving CDPI. The required drift velocities had to be of the order of, or greater than the Fermi velocities. While this is achievable in principle in very high quality samples, there are significant practical difficulties in realizing workable systems. In the present program we have developed a new approach to overcome these difficulties. The *modulated* systems mentioned above in section I, under appropriate conditions, require an order of magnitude smaller driving electric fields, and would thus make easier the experimental verification and device applications of this phenomenon.

III. Main Results.

There were three major areas covered in this program. We summarize below the main results:

1. Theoretical studies on modulated lower dimensional systems

A periodically modulated system with a small population in the highest mini-band acts as an electron gas with an effective Fermi momentum much smaller than the Fermi momentum of the unmodulated system of the same density. Consequently, a much smaller drift momentum (and a correspondingly smaller driving electric field) suffices to produce the plasma instability. We have investigated this phenomenon in detail (see Ref.1) for a model system consisting of a 1DEG with a periodic density modulation. Confining our system to a 2-miniband model we obtained the growth rates of CDPI for various driving field strengths. The main conclusion was that the modulated system gives rise to a strong instability at field strengths which are an order of magnitude smaller than those required for the corresponding unmodulated system. We also showed that the underlying physical principle for this instability was the creation of a velocity gap in the effective distribution function. Since this feature can be shown to survive for other lower dimensional systems, we have established that this is a very promising practical approach to achieve CDPI.

This calculation was based on certain simplifying assumptions. In a subsequent contribution³, we studied modulated 1DEG with arbitrary potentials, and also extended this approach to lateral surface superlattices (LSSL).

For typical parameters, the plasma wave frequencies as well as the electromagnetic radiation would be in the range $\omega \sim 10^{12} - 10^{13} \text{ sec}^{-1}$, and growth rates of the plasma instability are $\gamma \sim 10^{11} - 10^{12} \text{ sec}^{-1}$.

2. Exploration of possibilities for experimental verification

We have been in contact with Prof. Gornik and Prof. Hirakawa to set-up a program for experimental verification of these phenomena. Prof. Gornik (Vienna) has been interested in periodically modulated 2DEG, and has demonstrated a Smith-Purcell type, broad band, emission of radiation from such systems. Instead of 2D systems, modulated wires would constitute a preferable medium for CDPI. We have suggested that such a system be studied experimentally. Another promising system is a 2D electron gas modulated in both directions (LSSL). We have approached Prof. Smith (MIT), who has studied LSSL's in another context, to examine the feasibility of CDPI in such systems. Prof. Hirakawa (Tokyo) has been involved in various transport studies in lower-dimensional systems. We have suggested specific moderate field mobility studies in quantum wires to assess the parameter ranges, to be used as inputs in our calculations. The Workshop at Boston College was planned to set-up a suitable experimental verification program.

3. Current driven plasma instabilities in superconducting systems.

We have also continued our interaction with Prof. Graf of Boston College on his experimental program to study the feasibility of current-driven plasma instabilities in superconducting systems. A paper² was submitted to the 20th International Conference on Low Temperature Physics, which has been published in *Physica B*. Experimental evidence was presented for the existence of a current-driven plasma instability in superconducting films. Anomalous dissipation in a current carrying superconducting YBCO micro-bridge film was observed which was separated from a superconducting tin film by an insulating spacer layer. The results were consistent with the instability predicted⁴ for a system of two superconductors separated by an ideal interface, and with a relative drift of the carriers.

In conclusion, we have now identified theoretically the most promising candidates for CDPI in semiconductor based systems: *the modulated quantum wires and LSSL's*. Future work will be directed towards achieving experimental verification of this phenomenon in these systems. We have established close contacts with the leading experimental groups in these areas.

References for Section III

1. K. Kempa, P. Bakshi and H. Xie, "Current-driven plasma instabilities in modulated lower-dimensional systems", Phys. Rev. B48, 9158, (1993).
2. M.J. Graf, P. Bakshi, F.Dong, and K. Kempa, "Current driven plasma instabilities in superconducting systems", Physica B194-196, 2377,(1994).
3. P. Bakshi, K. Kempa, and H. Xie, "Current Driven Plasma Instabilities in Periodically Modulated Lower Dimensional Systems", Bull. Amer. Phys. Soc. 39, 805, (1994).
4. K. Kempa, J. Cen, P. Bakshi, " Current-Driven Plasma Instabilities in Superconductors", Phys. Rev.B39, 2852, (1989).

IV. Publications and Personnel.

a) Publications

1. K. Kempa, P. Bakshi and H. Xie, "Current-driven plasma instabilities in modulated lower-dimensional systems", *Phys. Rev. B*48, 9158, (1993).
2. M.J. Graf, P. Bakshi, F.Dong, and K. Kempa, "Current driven plasma instabilities in superconducting systems", *Physica B*194-196, 2377,(1994).
3. P. Bakshi, K. Kempa, and H. Xie, "Current Driven Plasma Instabilities in Periodically Modulated Lower Dimensional Systems", *Bull. Amer. Phys. Soc.* 39, 805, (1994).

b) Personnel

1. P. Bakshi (Faculty), Principal Investigator
2. K. Kempa (Faculty), Principal Investigator
3. H. Xie (Research Assistant)

c) Degree earned.

none

d) Reportable inventions.

None